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Interrill soil erosion as affected by tillage and residue cover

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Abstract

No-till cropping systems are effective in reducing soil erosion. The objective of this study was to determine whether high infiltration rates and low runoff and soil loss under long-term, no-till conditions in loessial regions of the Midwest US result from both the well-structured, porous condition of the soil and the protective cover of crop residue or primarily from residue cover. Soil loss, runoff, and infiltration were measured using a rainfall simulator on interrill erosion plots with and without residue cover on a conventional and two no-till systems in central Illinois. For both conventional till and no-till conditions, removing surface residue significantly decreased infiltration rates and increased soil loss. Tilling the no-till surface while maintaining an equal surface cover as with the no-till system slightly increased interrill erosion. Removing residue on a no-till system, however, increased soil loss significantly. A no-till soil condition without adequate residue cover will seal, crust, and erode with extremely high soil losses following surface drying.

Keywords: Soil erosion; No-till; Conservation tillage; Infiltration; Runoff; Residue management

1. Introduction

Conservation tillage systems are effective in reducing soil erosion because of greater crop residue cover, greater soil resistance to soil detachment, and transport or reduced soil erodibility, and often reduced runoff (Laflen and Colvin,

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1981; Lindstrom and Onstad, 1984; Stein et al., 1986; Edwards et al., 1988; Dick et al., 1989; West et al., 1991). Surface residue protects soil structural conditions at the surface from the energies of raindrop impact and surface flow. Aggregate breakdown, surface sealing and crusting, and clogging of worm holes or voids between structural units is reduced. Meyer et al. (1970) reported that 0.5 Mg ha^{-1} of straw mulch reduced soil loss to about one-third of that with no mulch cover, and that a rate of about 5 Mg ha^{-1} reduced soil loss by 95%. Lattanzi et al. (1974) showed that interrill erosion was reduced about 40% by wheat straw applied at 0.5 Mg ha^{-1} and about 80% by a rate of 2 Mg ha^{-1}. Maintaining a good soil surface structure enhances water infiltration and reduces runoff in well-drained soils. Even for soils that have increased runoff from no-till, for example, poorly drained soils or soils with restricting layers, soil loss is reduced because of protection of the soil surface from crop residue and greater surface resistance to sediment detachment. If surface residue is removed from a no-till system, however, the forces of a rainstorm will seal the soil surface and greater runoff and erosion occurs.

Both the amount of soil material detached by raindrop impact and that detached by surface flow are directly related to soil surface resistance or strength. The greater resistance to detachment forces results from greater bulk density and surface strength. Any disturbance of a no-till soil by tillage reduces that resistance. Increase in soil resistance with time (aging) following tillage is attributed to greater bulk densities and development of cohesive forces (Grissinger, 1972).

Whether high infiltration rates and low runoff and erosion under long-term, no-till conditions in the loessial regions of the Midwest US result both from the well-structured, porous condition of the soil and from the protective cover of the crop residue or primarily the residue cover has not been thoroughly analyzed. The objective of this study was to determine the effect of crop residue cover and soil tillage on the processes of interrill erosion on a conventional and two no-till systems in central Illinois. Soil loss, runoff, and infiltration were measured with and without residue cover using a rainfall simulator.

2. Materials and methods

Runoff, erosion, and infiltration were evaluated under simulated rainfall for two tillage treatments (no-till vs. disk) and a combination of residue coverage and soil disturbance. The study was conducted at three sites on the Printz and Kinsella farms near Lexington, IL, in early June 1992.

Site 1 was a conventional tillage field on the Printz farm and in a corn–soybean rotation. The previous crop was corn. Common tillage operations were chisel plow with twisted shank, tandem disk and field cultivator in the spring. Soil at the site is a moderately well-drained, Saybrook silt loam (fine-silty, mixed, mesic Typic Argiudoll). Selected soil properties of each site are given in Table 1. Treatments imposed on 1 m wide and 2 m long plots were: (1) freshly tilled (T–R) and (2) freshly tilled, with residue removed before tillage (T–NR). Residue cover was

Table 1
Selected soil properties of each soil studied

Site no.	Soil series	Percentage of particle size			Organic carbon (%)
		Sand (2-0.05 mm)	Silt (0.05-0.002 mm)	Clay (< 0.002 mm)	
1	Saybrook	7.4	79.7	12.9	2.3
2	Corwin	13.3	70.5	16.2	2.1
3	Saybrook	9.2	75.5	15.3	2.9

estimated by weighing the residue that was hand-removed from Treatment 2. Treatments were replicated six times.

Sites 2 and 3 were located in adjacent fields in a corn-soybean rotation on the Kinsella farm that had been in no-till for 15+ years. The previous crop on Site 2 was corn; on Site 3, soybeans. Soil at Site 2 is a moderately well-drained, Corwin silt loam (fine-loamy, mixed, mesic Typic Argiudoll); at Site 3, a Saybrook silt loam. Treatments at Site 2 were: (1) no-till (NT-R), (2) no-till with residue removed (NT-NR), (3) till with residue replaced on surface (T-R), and (4) till with residue removed (T-NR). For Treatments 3 and 4, crop residue was removed and plots were tilled by hand hoeing. Residue was replaced on Treatment 3 plots. Treatments at Site 3 were: (1) no-till (NT-R), (2) no-till with residue removed (NT-NR), (3) till with residue removed prior to tillage (T-NR), and (4) Treatment 3 repeated after three soil-drying days. All treatments were replicated six times. Soil loss at Site 3 was determined for two time periods, in early June and again in early October following corn harvest.

Rainfall at an intensity of 70 mm h^{-1} was applied to each plot for 90 min using a programmable rainfall simulator. For the runs in October on Site 3, initial rainfall intensity was 100 mm h^{-1}, followed by intensities ranging from 50 to 150 mm h^{-1} to create different levels of runoff. The rainfall simulator was located 3.0 m above each plot and used oscillating Veejet 80150 nozzles (Spraying Systems Co., Wheaton, IL, USA). Runoff (q) and soil loss (E) were measured at 5 min intervals throughout the run. Infiltration rate was calculated as the difference between rainfall and runoff. On selected plots following rainfall, bulk density and fall-cone strength was determined (Bradford and Grossman, 1982). Sediment size distribution was determined on sediment samples collected after 55 and 85 min of rainfall.

3. Results

Residue cover by weight at each site immediately preceding the study are given in Table 2. Percent cover at Site 1 was estimated to be 12%. At the no-till sites corn residue cover was near 100% and soybean cover about 60%. Fall-cone strengths for a matric potential of -0.5 kPa and soil bulk densities are also listed in Table 2.

Table 2
Fall-cone strength, bulk density, and residue cover at three sites

Site no.	Tillage/cropping treatment	Fall-cone strength (kPa)	Bulk density ($g\,cm^{-3}$)	Residue cover	
				Mass ($kg\,m^{-2}$)	Percent (%)
1	Conventional till	5.8	0.87	0.26	12
2	No-till/corn residue	17.3	1.03/1.19[a]	1.12	100
3	No-till/soybean residue	13.5	1.18	0.64	60
3	No-till/corn residue (October)	–	–	1.06	95

Fall-cone strength and bulk density measured at soil matric potential of −0.5 kPa.
[a]Non-wheel track/wheel track.

Table 3
Final infiltration (FIR) and soil loss rates after 90 min of simulated rainfall (70 mm h^{-1}) in June 1992

Tillage/ residue cover treatment[a]	Site 1, conv. till		Site 2, no-till, corn		Site 3, no-till, soybean	
	FIR ($mm\,h^{-1}$)	Soil loss ($kg\,m^{-2}\,h^{-1}$)	FIR ($mm\,h^{-1}$)	Soil loss ($kg\,m^{-2}\,h^{-1}$)	FIR ($mm\,h^{-1}$)	Soil loss ($kg\,m^{-2}\,h^{-1}$)
NT-R	–	–	70.0+	0.01	70.0+	0.01
NT-NR	–	–	52.9	0.13	41.2	0.16
T-R	62.1	0.13	66.1	0.04	–	–
T-NR	39.2	0.52	35.2	0.59	32.4	0.76
T-NR (crusted)	–	–	–	–	20.1	1.21
LSD (0.05)	4.9	0.22	8.0	0.18	4.7	0.12

Infiltration and soil loss were calculated from runoff and sediment samples collected 85–90 min into the rainfall period.
[a]Treatments are no-till with residue (NT-R), no-till with residue removed (NT-NR), freshly tilled with residue (T-R), and freshly tilled with residue removed (T-NR).

3.1. Soil loss and infiltration – June 1992

Summaries of average final soil loss and infiltration rates during the 85 to 90 min sampling period for the June runs are shown in Table 3. At Site 1, the conventional tillage site, removing the surface residue (0.26 kg m^{-2}) decreased infiltration rates from 62.1 to 39.2 mm h^{-1} and increased soil loss from 0.13 to 0.52 kg m^{-2} h^{-1}. Thus even though percent surface cover was 12% in plots where residue was not removed, a significant level of protection of the soil surface condition was achieved compared with residue removal.

At Site 2, a no-till field previously in corn, runoff and soil loss rates were essentially equal to zero. Removing surface residue from the no-till condition decreased infiltration rates and increased soil loss rates. By disturbing or tilling the no-till surface and maintaining an equal surface cover as with the no-till system, the change in infiltration rate and soil loss was less than by removing the residue and not disturbing the soil surface. In other words, the surface residue cover ef-

Table 4
Sediment size (mean weight diameter in millimeters) of sediment collected during the final 5 min of a 90 min rainfall of 70 mm h^{-1}

Treatment[a]	Site 1	Site 2	Site 3
NT-R	-	0.23	0.18
NT-NR	-	0.24	0.19
T-R	0.26	0.25	-
T-NR	0.26	0.26	0.24
T-NR (dried)	-	-	0.18

[a]NT, no-till; T, till; NR, residue removed; R, residue.

fect was greater than the soil disturbance effect in maintaining high infiltration rates and reducing soil loss. When both the soil structural condition was disturbed by tilling and the residue was removed, final infiltration rate was greatly reduced (from 70+ to 35 mm h^{-1}) and the erosion was greatly increased (0.01 to 0.59 kg m^{-2} h^{-1}).

At Site 3 under no-till conditions, the entire 105 mm of rain infiltrated the soil and only 0.01 kg m^{-2} h^{-1} erosion occurred. Removing the residue again significantly decreased infiltration rate and increased soil loss. Removing the residue and tilling the surface further decreased infiltration rate and increased soil loss. Following a 3-day period of drying on the tilled with no residue treatment plots, even greater decreases in infiltration and increases in soil loss occurred. The soil loss was increased to 1.21 kg m^{-2} h^{-1}.

As seen in Table 4, little differences in sediment size transported existed among locations and tillage and residue cover treatments.

Comparisons among tillage treatments are not statistically valid because site and tillage treatments are confounded. Data in Table 3 shows, however, that where the residue was not removed slight soil loss occurred on the no-till plots and the entire rainfall amount at 70 mm h^{-1} for 90 min infiltrated the profile. Where the no-till structure was destroyed by tillage and residue was removed, soil loss rates were high. Where the soil was allowed to dry and then rainfall again applied, soil loss was further increased. This later condition is typical of natural conditions existing from the period following seed bed preparation until complete canopy cover. For this condition, soil loss exceeds the soil loss tolerance or *T* value of 1.1 kg m^{-2} (Soil Survey Staff, 1992), even at the end of 1 h.

3.2. Soil loss and infiltration – October 1992

Table 5 shows the equilibrium or average final infiltration and soil loss rates for Site 3 following corn harvest for a rainfall intensity of 100 mm h^{-1}. Removing the residue cover greatly decreased the final infiltration rate, regardless of tillage treatment. Coversely, the tillage effect on final infiltration was small in the cases of both residue or no residue cover. For soils with high residue cover, the effect of tillage on soil loss was low. The residue cover effect on soil loss was extremely

Table 5
Equilibrium infiltration and soil loss rates for Site 3 (no-till, following corn harvest) in October 1992 (rainfall intensity = 100 mm h^{-1})

Tillage/residue cover treatment	Infiltration ($mm\ h^{-1}$)	Soil loss ($kg\ m^{-2}\ h^{-1}$)
No-till, residue	87.7	0.01
No-till, residue removed	26.2	0.94
No-till, residue removed (dried, crusted)	15.0	1.96
Till, residue	89.3	0.02
Till, residue removed	32.2	2.45
Till, residue removed (dried, crusted)	21.4	3.77

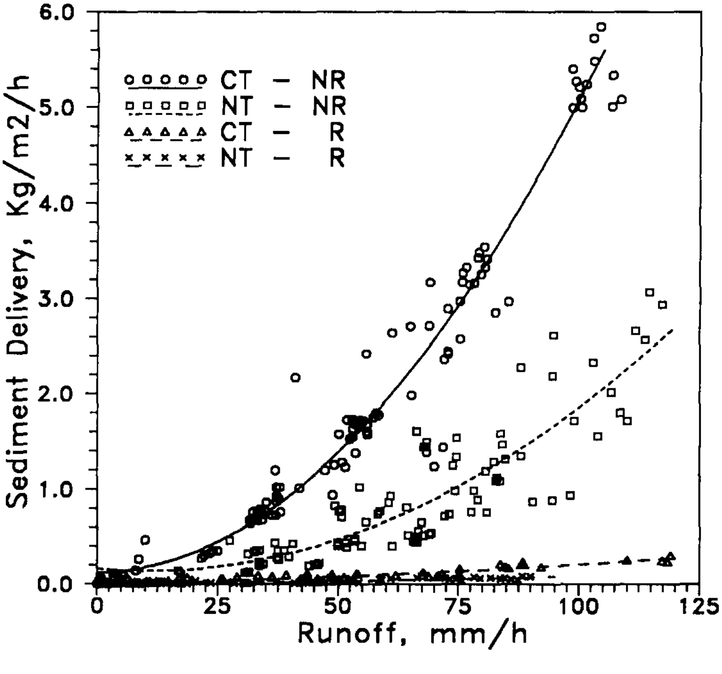

Fig. 1. Kinsella Farm Field Study, October 5–14, 1992. Soil: Saybrook silt loam. Crop: no-till corn after harvest; previous year soybeans. Treatments: T-NR, tilled, surface residue removed; NT-NR, no-till, surface residue removed; T-R, tilled, with residue; NT-R, no-till, with residue. Rain intensities: T-NR, NT-NR—50, 70, 100, 125 mm h^{-1}; T-R, NT-R—100, 125, 150 mm h^{-1}

large for tilled soil; for bare soil, the undisturbed soil (no-till) was 0.38 as erodible as the tilled soil. Soil loss on a dried, crusted surface with residue removed was less for the no-till compared with tilled treatment owing to greater soil resistance of the no-till soil surface, even though runoff was greater for the no-till treatment.

Soil loss is expressed in terms of runoff in Fig. 1. For a specific runoff rate, sediment yield values were low for both no-till and tilled conditions with residue, high for no-till without residue and even higher for tilled with residue removed.

4. Discussion and conclusions

Erosion on conventional tillage plots depends largely on: (1) amount of residue cover, (2) roughness, (3) antecedent moisture, and (4) drying following rainfall. Erosion under no-till conditions depends primarily on residue cover or the amount of protection on the soil surface from raindrop energy (Laflen and Colvin, 1981; Cogo et al., 1984; Lindstrom et al., 1984). Since both no-till and conventional treatments were not conducted at each site, comparison of the effect of tillage on runoff and erosion cannot be made statistically. Surface residue and soil disturbance effects on infiltration and erosion were evaluated.

For the no-till with residue treatment, infiltration rate remained high because surface pores were protected from rainfall energy (Norton, 1987; Freebain and Gupta, 1990). A surface seal cannot form because of surface soil resistance greater than energy available for soil structural breakdown. Sediment yield was low because of low soil detachment rates and few detached particles available for transport.

For the tillage with residue treatment, infiltration rate remained high because of stable surface aggregates and insufficient raindrop energy to break down aggregates (the 60 min infiltration rate was 87.7 mm h^{-1} for NT and 89.3 mm h^{-1} for T and final infiltration rate was 65.5 mm h^{-1} for NT and 53.4 mm h^{-1} for T). Some sealing occurred owing to rapid wetting and aggregate breakdown. Sediment delivery was higher for tilled than no-till conditions because of aggregate breakdown by tillage, of exposure of surface aggregates to raindrop impact, and because of availability of small, loose surface aggregates for transport.

Comparing no-till (NT) with till (T), both with surface residue removed, runoff occurred sooner on NT because of rapid filling of surface pores and clogging of pores by raindrop splash. Runoff occurred later for tilled conditions because of greater surface roughness and depressional storage (Mohamoud et al., 1990). Final runoff and infiltration rates were about the same for NT vs. T because surface seal properties are primarily responsible for runoff and infiltration rates, not what occurs below the seal. Sediment delivery was a totally different issue. Because NT had greater soil strength or resistance ($NT=T\times 3$), detachment was much less in NT and, therefore, sediment delivery in NT was much less. In T, detachment was much greater, more sediment was available for transport, surface flow was more concentrated, and sediment delivery was greater. Sediment delivery increased following a drying period owing to further weakening of the seal by drying and by rapid wetting by raindrops. Since the surface seal of Saybrook soil was not strong enough to prevent splash, sediment remained available for transport (even though the infiltration rate had stabilized at a low value). Equally low infiltration rates existed for dry NT and T, but sediment delivery for dry NT was 1/2 of dry T because of a denser and stronger matrix.

From the results of this study on three similar soils, we conclude that residue management is much more important than soil management. Without adequate surface residue, even a no-till soil condition will seal, crust, and erode. It is the combination of residue cover and improved soil structure that causes reduced runoff and erosion. Furthermore, no-till can increase soil stability and support for tractors and harvesting equipment.

Differences in runoff and soil loss between conservation and conventional tillage systems is most pronounced immediately following tillage. As the crop canopy begins to protect the soil surface from raindrop impact, sealing and crusting of the soil surface is greatly reduced and differences in infiltration rates between conventional and reduced tillage lessen. Even for drier climates with a low probability of high intensity rainfall following disking and seeding and preceding canopy cover, the soil surface must be protected to lessen surface sealing and crusting.

For years with low rainfall during the period from seeding to complete canopy cover, strong surface seals and crusts are unlikely to develop and infiltration rates not likely to be affected. For the period following canopy cover, there will be small differences between infiltration and erosion for no-till and conventional tillage treatments. In most years in the Midwest, rainfall does occur during the period preceding canopy cover. For McLean Co., Illinois, 2 years in 10 will have precipitation more than 131 mm in April, 130 mm in May, and 153 mm in June (Soil Survey Staff, 1992). High intensity rainfall will form a strong seal on most soil conditions, ranging from freshly tilled to no-till, without residue cover. Drying of the seal and the formation of a crust disrupts the seal. Initially the crust has a high infiltration rate but a strong seal quickly redevelops causing increased runoff and soil loss rates compared with the initial seal. Following complete canopy cover, the infiltration rate for a dried crust will remain relatively high because of insufficient raindrop impact energy to reform the seal. Thus infiltration rates will remain high and runoff relatively low throughout the growing season. Under natural conditions, a no-till crust will normally not exist, unless the soil is structurally unstable, because residue levels most likely will remain high throughout the period from planting to complete canopy cover. During the growing season, residue cover levels diminish but the plant canopy now protects the soil surface.

Data from this experiment also show a need to develop erosion models based on fundamental erosion processes of detachment and transport and soil processes such as seal formation and surface drying. Soil erosion for no-till conditions is presently treated in the Universal Soil Loss Equation (USLE) and Revised USLE by adjusting the C factor. Since it is essentially impossible to establish a standard state condition for determining soil erodibility (the K factor) and since the C-factor term for no-till conditions is highly empirical, erosion models must consider incorporating a range of soil conditions, such as no-till, in the K factor term.

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